

Cosmic Frontier at Brookhaven

Anže Slosar, Andrei Nomerotski

Comparative Lab Review on
Cosmic Frontier Research 2016



Plan for the presentation

- ▶ Anže Slosar: General introduction (5mins)
- ▶ Andrei Nomerotski: LSST project and science (15 mins)
- ▶ Anže Slosar: LSST DESC and DES science (10 mins)
- ▶ Anže Slosar: Group activities and conclusions (5 mins)

BNL Cosmology & Astrophysics Group



Andrei Nomerotski



Erin Sheldon



Anže Slosar

- + outgoing postdocs (Cieplak, Vazquez, Fisher-Merline)
- + support at Instrumentation Division

Comparative Review 2013

From the CR2013 review:

The BNL Cosmic Frontier group is small but has strong contributions to current dark energy experiments (DES/BOSS). The panel does not see clearly how the science staff will work synergistically with the large LSST project effort at the lab. The transition path from current dark energy experiments to LSST is not yet clear.

We have spent the last three years addressing this comment. We have done so by:

- ▶ realigning current staff (Sheldon, Slosar), hiring new staff (Nomerotski)
- ▶ strengthening links between group and project work
- ▶ becoming integrated and active in Dark Energy Science Collaboration (DESC)

Cosmic Frontier at BNL

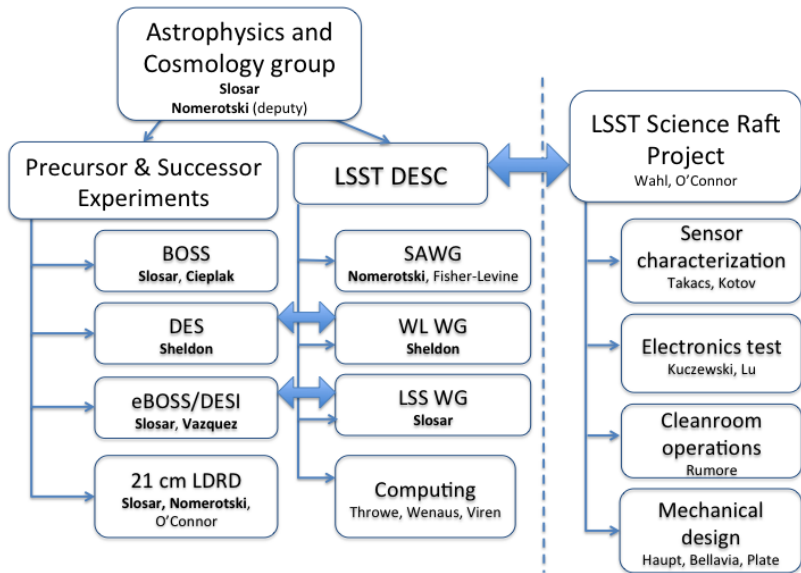
- ▶ Focus on **LSST Science**:
 - ▶ leadership roles DESC management (**Nomerotski**, **Slosar**)
 - ▶ leadership roles in DESC infrastructure (**Sheldon**)
 - ▶ leadership roles in science (**Nomerotski**, **Sheldon Slosar**)
 - ▶ strong connection to raft production in Instrumentation Division (**O'Connor**, **Wahl**, **Takacs**, **+N**)
- ▶ Involvement in LSST precursor **DES** (**Sheldon**)
- ▶ Minor/continuing roles in **BOSS**, **eBOSS**, **DESI**, (**Slosar**, **Vazquez**)
- ▶ **DOE service tasks** (**Sheldon** reviewing university grants, **Slosar** serving on Cosmic Visions Dark Energy panel)
- ▶ Color coding:
 - ▶ **staff**
 - ▶ **postdocs**
 - ▶ **Instrumentation Division Scientists**

LSST project at BNL

In Instrumentation Division:

- ▶ At the moment there is \$4.6M of LSST project funding flowing through Instrumentation Division
- ▶ In total **25** people, **14 full time**, excluding Cosmology & Astrophysics group in Physics
- ▶ subsystem manager and Physicist for the Camera Science Raft
- ▶ **2 FTEs** funded through lab overhead
- ▶ BNL deliverable: tower raft modules containing focal plane sensors and driver / readout electronics
- ▶ BNL deliverable is performance and schedule critical
- ▶ **LSST is a major activity at BNL**
- ▶ **The Cosmology & Astrophysics group was created to support this activity in science**

Cosmic Frontier at BNL



BNL's role in LSST DESC

- ▶ 7 Full Members (Nomerotski, May, Sheldon, Slosar, O'Connor, Wenaus, Fisher-Levine)
- ▶ Active in
 - ▶ Large Scale Structure (Slosar)
 - ▶ Sensor Anomalies (Nomerotski)
 - ▶ Weak Lensing (Sheldon)
- ▶ BNL collaborators helped write large part of Large Scale Structure and Sensor Anomalies sections of the **Science Roadmap** (SRM)

DESC Leadership roles

- ▶ **Andrei Nomerotski:**

- ▶ co-convenor of Sensor Anomalies Working Group
- ▶ Chair of the DESC Membership committee
- ▶ past member of Collaboration Council

- ▶ **Erin Sheldon:**

- ▶ Technical lead for WL pipeline (new position) in FY17
- ▶ In discussion with DESC management to partly support him on DESC operations funding
- ▶ WL working group convenor in DES (LSST precursor)

- ▶ **Anže Slosar:**

- ▶ co-convenor of Large Scale Structure Working Group
- ▶ elected member of Collaboration Council
- ▶ drafted *DESC Code of Conduct*
- ▶ member of the Meetings Committee
- ▶ member of the LSST Science Advisory Committee (LSST project role)

BNL's role in LSST Camera Project

- Sensor R&D and characterization in 2005-2013
- “Vertical slice” testing of CCD and electronics chain
- Camera Science Raft Construction in 2015-2019
 - BNL has lead role in designing and delivering the Science Rafts
 - 150m² Class 1000 cleanroom for raft production

BNL Science Raft Team in Instrumentation

Ron Angona
Steve Bellavia
Rebecca Coles
Jason Farrell
Justine Haupt
Bernie Kosciuk
Ivan Kotov
John Kuczewski
Jessica Li
Wei Lu
Michelle
McQueen
Connor Miraval
Homer Neal

Paul O'Connor*
Steve Plate
Dan Puleo
Sean Robinson
Matt Rumore
Peter Takacs
Brian Walsh
Bill Wahl**

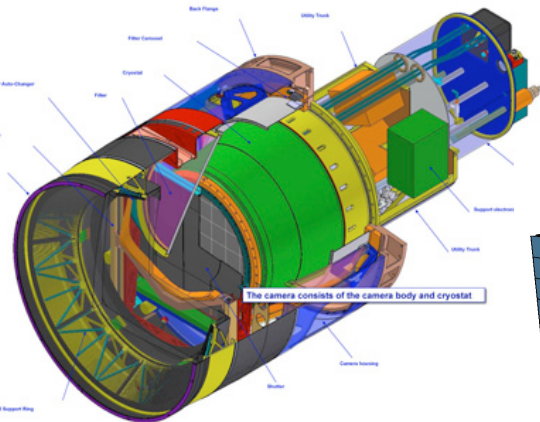
* Subsystem physicist

** Subsystem manager



Large Synoptic Survey Telescope

The Camera Design Overview

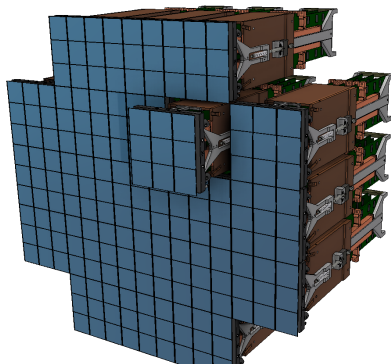


3 Gigapixel Camera

3.5° (64cm)

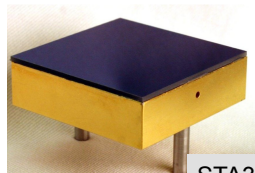
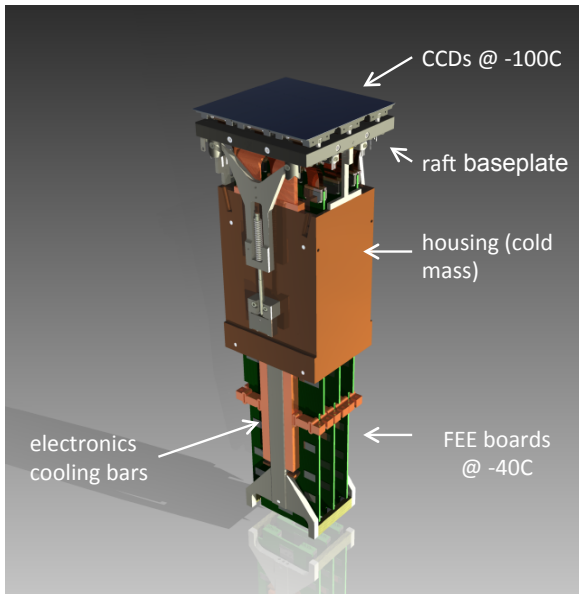
189 CCDs

21 Science Raft modules



LSST Focal Plane

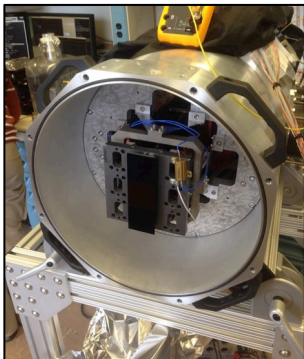
Raft Tower Module



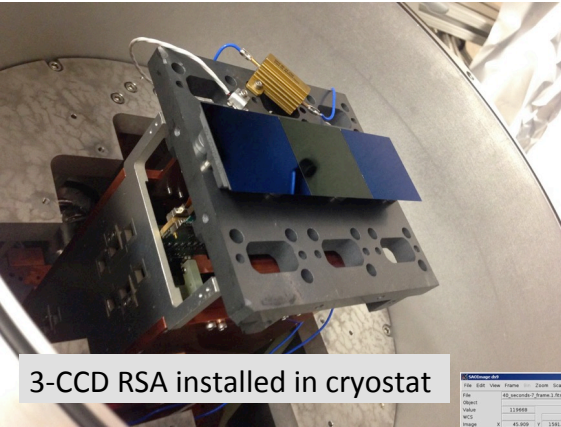
STA3800

4k x 4k = 16 Mpixels
10x10 microns pixel

LSST Cleanroom, commissioned in 2013



Vertical Slice Test - Integration of LSST sensors and readout electronics

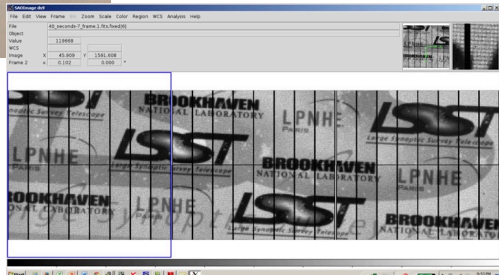


3-CCD RSA installed in cryostat

- Collaborative work of many LSST institutions

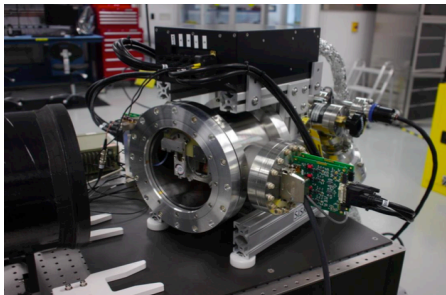
Imaging with full readout chain

- Low noise performance achieved at BNL in 2014



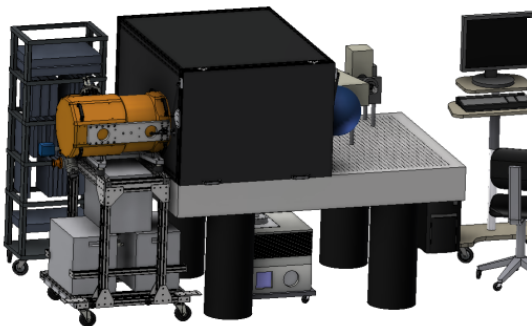
Our sensor expertise is available to the Camera project

- Commissioning of teststands in cleanroom
- In depth testing of production sensors (QE, CTE, spider legs etc)
- Supervision of off-project manpower (students and postdocs) working in the cleanroom and on the sensor data analysis
 - [Stony Brook, Wayne State, Oxford, BNL SULI undergrads](#)
- Astro computing cluster is used to process and transfer testing data to LSST data catalog at SLAC

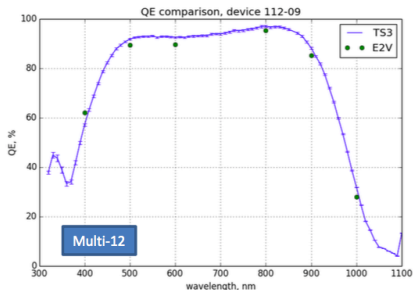


TS3 in the cleanroom

Example: EO testing in Test Stand 3 and 8



TS8 in the cleanroom



QE vs wavelength

Performed absolute QE calibration for TS3, in the process of commissioning of TS8

Sensor Anomalies WG

- DESC technical group, co-chaired by Nomerotski from inception in 2015
- Main focus on CCD signatures, important for precision astrometry and photometry in LSST, WL is one of strongest motivations
- Major effort in 2015 to define ways forward and priorities in DESC Science Road Map

SLAC

Search

- General
- Getting Started
- Collaboration Organization
- Analysis WGs
- Computing WGs
- Technical WGs
 - wiki page for filter and SN task
- Observing Strategy
- Sensor Anomalies Working Group
- Photometric Corrections Working Group
- Taskforces 2015-16
- Collaboration Meetings
- Admin
 - SS and CS Planning
 - Arza's scratch space
 - File lists

LSST Dark Energy Science Collaboration / Home / Technical WGs

Sensor Anomalies Working Group

Created by Andrei Nomerotski, last modified on Apr 27, 2016

Mission:

- characterization of sensor features and anomalies;
- validation of sensor effects implemented in simulations;
- validation of signature removal algorithms in DM;
- propagation of the sensor effects in to systematic uncertainties of science observables;
- in-depth testing of production sensors.

SAWG section in Science Roadmap (SRM2015) SRM tasks sign up page

Meetings & Communications:

[SAWG Meetings page](#)

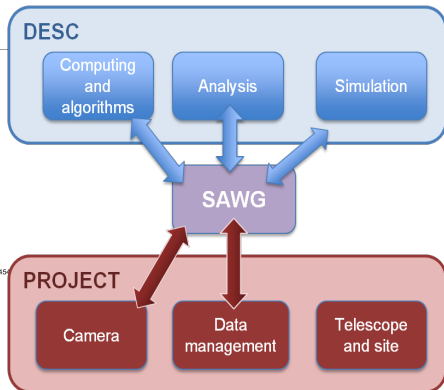
[SAWG room in DESC HipChat](#)

Organization:

SAWG leads: Andrei Nomerotski (BNL), email anomerotski@AT.bnl.gov; tel 631 3448338 or 631 4887450

The table below shows coordination between on- and off- project activities and the sign-off process:

stage	on-project	off-project	coord & sign-off
anomaly identification	sensor team	SAWG	camera scientist
characterization &		DESC labs	SAWG lead

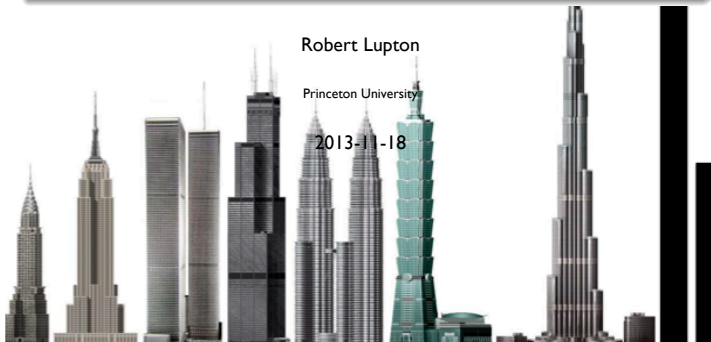


LSST pixel : $10 \times 10 \times 100 \text{ micron}^3$

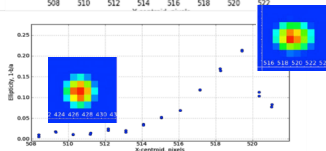
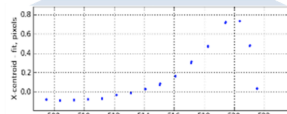
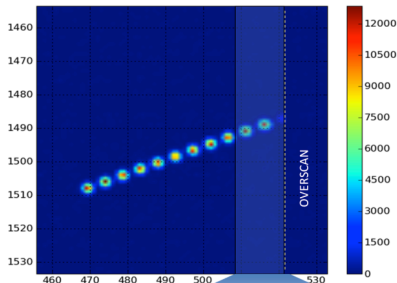
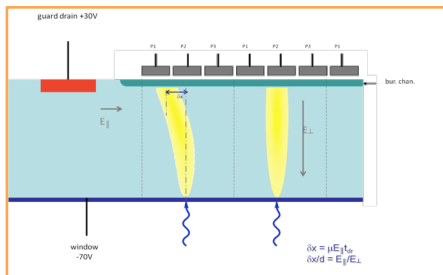
→ Pixels are skyscrapers

1930	1931	1972/73	1974	1997	2004	2010	2013	2022
Chrysler New York 1046 ft 77 Stories	Empire State New York 1250 ft 102 Stories	World Trade Center New York 1368 ft 110 Stories	Sears Tower Chicago 1450 ft 110 Stories	Petronas Towers Kuala Lumpur 1483 ft 88 Stories	Taipei 101 Taipei 1,671 ft 101 Stories	Burj Khalifa Dubai 2717 ft 162 Stories	HSC	LSST

Consequences of thick CCDs on Image Processing



Astrometric Distortions in Thick CCDs

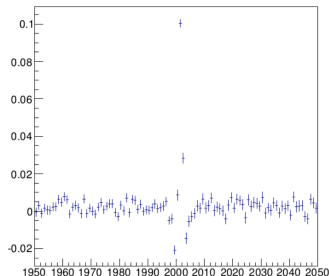
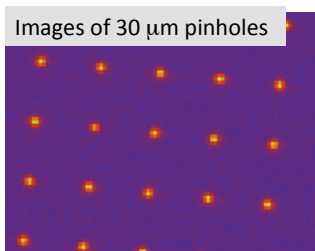
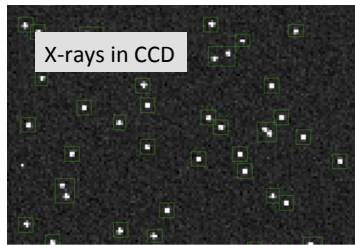


Astrometric distortion studies

Studies in the lab by O'Connor,
Nomerotski and students

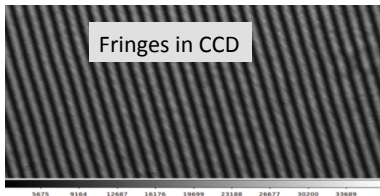
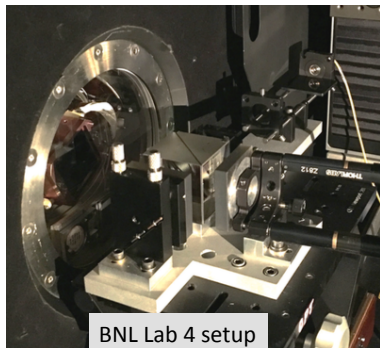
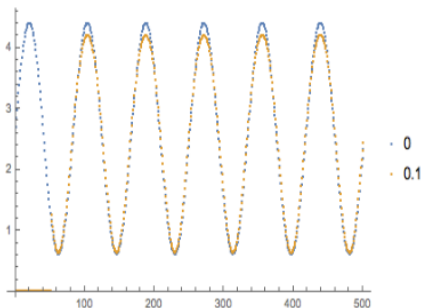
- X-rays
- Pinholes
- Fringe projector

Use DM stack analysis framework and
shape fitting code (ngmix) by Sheldon



Fringe projector

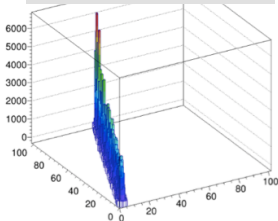
- Nomerotski, Takacs and Gilbertson (SULI student)
- Michelson interferometer to generate sinusoidal fringes
- Excellent tool for studies of Brighter Fatter effect and for separation of astrometric and photometric effects



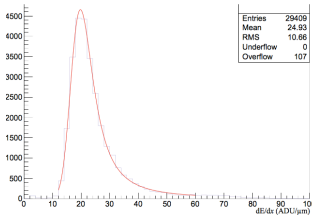
More CCD characterization

- Fisher-Levine used cosmics to measure gain and diffusion in LSST CCDs, applied analysis to DES data

Cosmic ray in LSST CCD

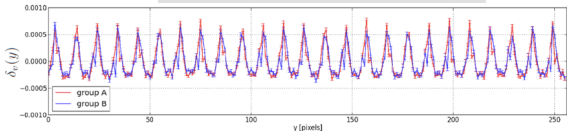


dE/dx in CCD

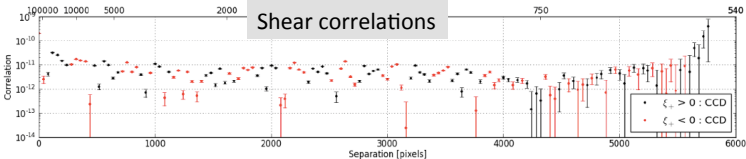


- Okura and May looked for pixel size variations in recent CCD prototypes, calculated shear correlations due to this

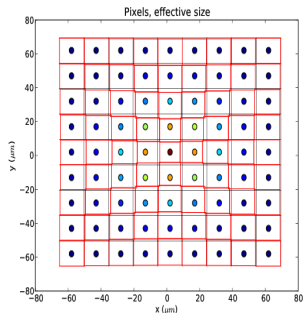
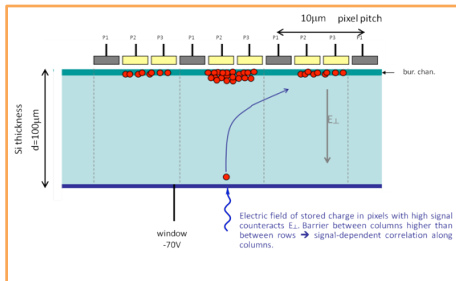
Pixel response variation in flats



Shear correlations



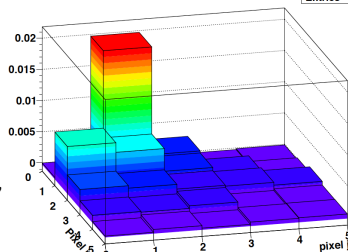
Brighter-Fatter Effect



Astier et al

correlation CCD E2V @ 73ke

amp. #4
Entries 24



Pixel correlations

24 / 41

- Major effort to model BF effect, coordinated by SAWG
- Contributions by BNL, Paris (Astier et al), UC Davis (Lage), Duke (Walter), SLAC (Rasmussen)
- After two years:
 - Good understanding of underlying physics
 - Same parameters describe both PSF and flux correlations
- Discussions with WL WG on required precision, 10% achieved

Sensor Simulations

LSST Photon Simulator
(Peterson, Rasmussen et al) :

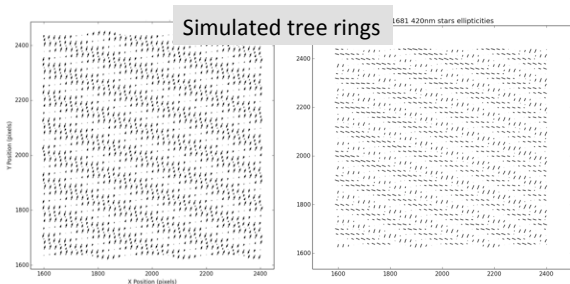
Propagates single photons
accounting for atmosphere,
optics and sensors

Nomerotski and Beamer (SBU
student) worked on validation
of sensor effects in Phosim

Tree rings

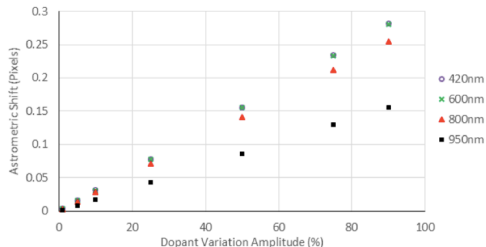
Edge effect

Fringes in IR



Astrometric shifts

Ellipticity



Astrometric shift vs Dopant variation

MonoCam-I: NOFS in May 2016

Motivations: astrometry and photometry with LSST sensors, sensor studies with sky data, atmospheric studies

- Close coordination with DESC Photometric Corrections WG and DM

Organized by Nomerotski, collaboration with D.Monet at Naval Observatory Flagstaff Station (NOFS), used two telescopes: 61-inch and 1.2m

- Scale plate similar to LSST
- Seeing 1-2 arcsec
- SDSS filters + y + Ronchi grating

Used single e2v CCD and Reflex readout in BNL Lab4 dewar

Total 6 good nights for observations, lots of data



MonoCam at 1.2 m telescope

MonoCam reduction and analysis

Reduction by Fisher-Levine with DM help (Lupton, Price et al)

- Good link to DM activities, DM tried for the first time on proper LSST sensors

Astrometric analysis

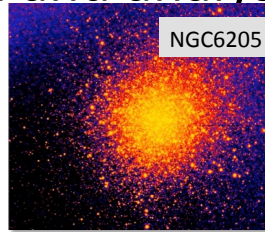
- Use astrometric residuals to map sensors effects, close the loop for DM corrections

Photometric analyses:

- Ronchi grating (Harvard and Paris)
- CALSPEC stars (Paris)
- y and z-bands fringing (BNL)

Sensor studies

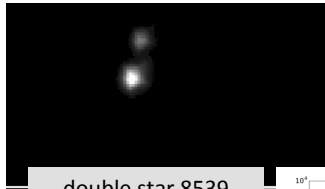
- Voltage and filter scans (BNL)
- Exposure time scans (BNL)



NGC6205



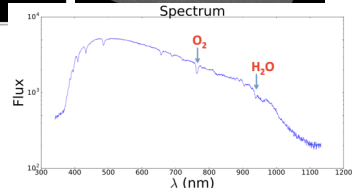
HD163466, Ronchi grating



double star 8539
1.4 arc sec separation

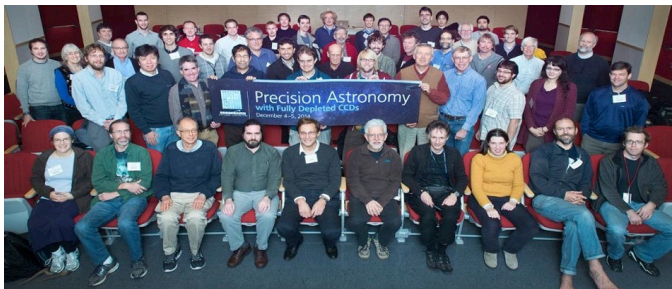


M51 Whirlpool galaxy in grz

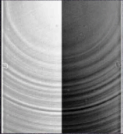
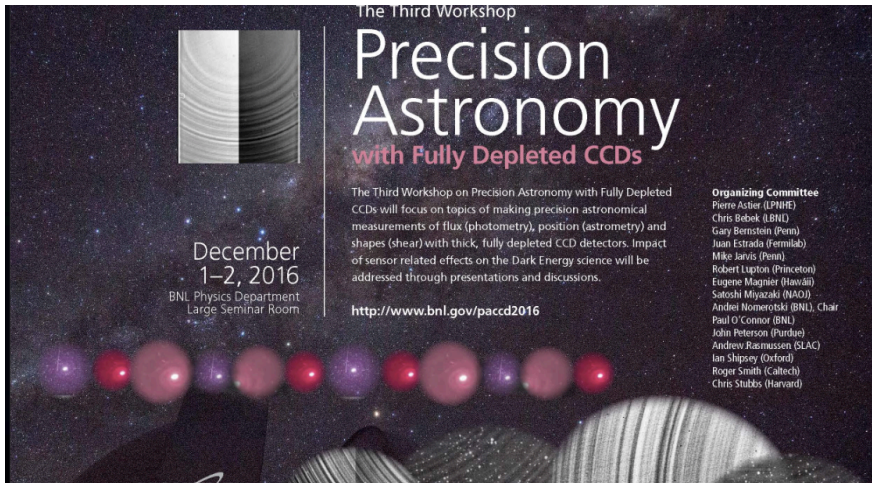


Moniez et al

PACCD Workshops in 2013 and 2014



3rd workshop “Precision Astronomy in Fully Depleted CCDs” on Dec 1-2 2016 at BNL



The Third Workshop

Precision Astronomy

with Fully Depleted CCDs

December 1–2, 2016
BNL Physics Department
Large Seminar Room

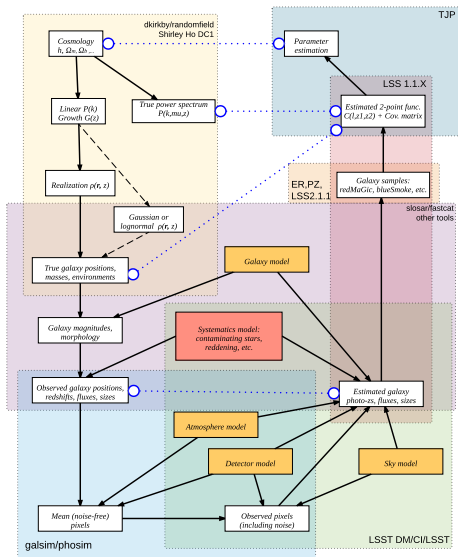
The Third Workshop on Precision Astronomy with Fully Depleted CCDs will focus on topics of making precision astronomical measurements of flux (photometry), position (astrometry) and shapes (shear) with thick, fully depleted CCD detectors. Impact of sensor related effects on the Dark Energy science will be addressed through presentations and discussions.

<http://www.bnl.gov/paccd2016>

Organizing Committee
Pierre Astier (LPIHE)
Chris Bebek (BNL)
Gary Bernstein (Penn)
Juan Estrada (Fermilab)
Mike Jarvis (Penn)
Robert Lupton (Princeton)
Eugene Magnier (Hawaii)
Satoshi Miyazaki (NAOJ)
Andrei Nomerotski (BNL), Chair
Paul O'Connor (BNL)
John Peterson (Purdue)
Andrew Rasmussen (SLAC)
Ian Shipsey (Oxford)
Roger Smith (Caltech)
Chris Stubbs (Harvard)

DESC Large Scale Structure WG

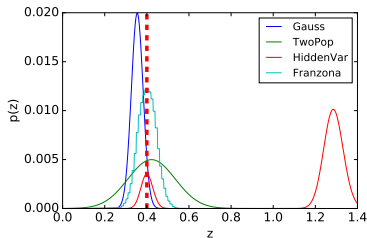
- ▶ co-chaired by **Slosar** since January 2016
- ▶ Slosar wrote over half of LSS section of SRM in Fall 2015
- ▶ Ramping up of actual work in place of perpetual planning
- ▶ 2pt validation project is closing the loop between creating mock data with known answer and extracting information
- ▶ lots of work needs to be done between now and first light in order to have coherent, validated and optimal framework in place



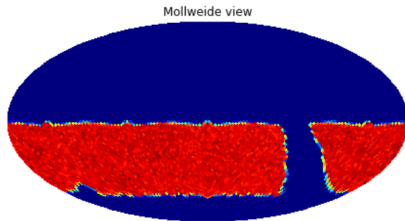
code-validation process chart [Slosar/Kirkby]

2-point validation project

- ▶ Lognormal mocks provide a quick short-cut to “realistic enough” galaxy fields
- ▶ These fields can be mocked using the full complexity, to create toy problems to study systematic effects one by one:
 - ▶ photo-z errors
 - ▶ depth fluctuations
 - ▶ stellar contamination
 - ▶ blending
 - ▶ ...
- ▶ In contrast to DCx challenges, we can have $O(1000)$ mocks, allowing systematic statistical testing
- ▶ Basic framework in place



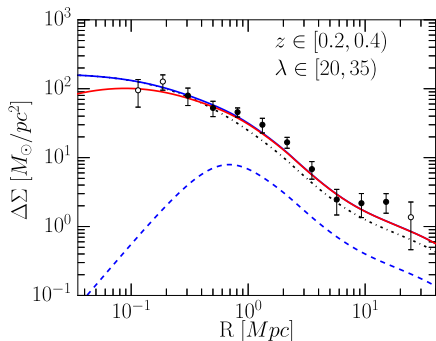
Different photo-z models developed for 2-pt validation



Window function for lognormal mocks based on OpSim runs

Dark Energy Survey (DES)

- ▶ **Sheldon** involved at 80% effort
- ▶ Ideal test-bed precursor to LSST
- ▶ Sheldon developed one of the two officially sanctioned shear pipelines
- ▶ 46 DES science papers published or submitted
- ▶ Paper on lensing by clusters of galaxies, initiated by E. Sheldon, now in final stages. Part of the DES key project to constrain cosmology from clusters and lensing.
- ▶ Sheldon continues to make experiment agnostic WL research that will naturally transition to LSST:
 - ▶ Theoretical paper on Metacalibration (originally proposed by Huff) in preparation
 - ▶ Sheldon demonstrating Metacalibration is viable in real data using DES



Mass Density Constrast
of DES Clusters.

Sheldon LSST Work

- ▶ Galaxy measurement code is interesting for LSST
 - ▶ An order of magnitude faster than standard codes.
 - ▶ Can fit multiple epochs and multiple bands simultaneously.
Important for LSST with very large number of epochs, many bands.
 - ▶ Multi-object fitting is running in DES data
- ▶ Working with LSST data management (Perry Gee, Robert Lupton) to integrate code
- ▶ This work will evolve into LSST DESC pipeline work

University connections

▶ **Stony Brook:**

- ▶ Nomerotski and Slosar have shared PhD students through BNL-SB seed program
- ▶ Joint SB-BNL Cosmology Seminar Series
- ▶ SB hired 2 cosmology faculty, 2 more “shared with BNL” written into BSA re-compete contract
- ▶ Anja von der Linden is DESC cluster WG convenor
- ▶ project paying for a SB grad student in the cleanroom

▶ **Harvard:**

- ▶ Regularly work with Stubbs' group in instrumentation issues
- ▶ collaborated on monacam (see AN talk)

▶ **Princeton:**

- ▶ strong connections on data reduction and management
- ▶ postdoc Fisher-Levine partly funded by Princeton, moving there in fall to work with Lupton on LSST DM

▶ **Oxford:**

- ▶ Will station one postdoc in fall 2016

University connections

- ▶ **University of Pennsylvania :**
 - ▶ Sheldon and Jarvis (U. Penn) co-convene the DES Weak Lensing shear pipeline working group and collaborate closely on WL science
- ▶ **RIKEN:**
 - ▶ Yuki Okura, paid by RIKEN, works with Morgan May
- ▶ **Duke:**
 - ▶ Funded two summer students in 2014
- ▶ **Wayne State:**
 - ▶ One student **supported on SCGSR** to measure LSST CCD quantum efficiency

Conferences for cosmology community:

► Cosmic Visions DE East Coast

- 1st October, 2015
- East Coast Local meeting to gather input to Cosmic Visions DE panel
- Organized by Slosar
- Good attendances, input for document presented to DOE in Feb 2016

► Cross-correlation Spectacular 2016:

- 23-26 May, 2016
- Organized by Slosar, Sehgal (SB)
- Representation from all major experiments: WFIRST, Euclid, DESI, PFS, HSC, SphereX, ...
- Secured \$11,000 external funding to pay for students
- Great Success!

► Precision Astronomy with CCDs 2016:

- Covered in AN talk

► LSST DESC Collaboration Meeting 2017

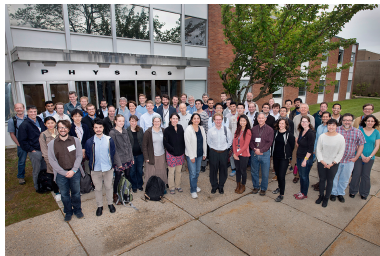
Cosmic Visions Dark Energy: Science

Scott Dodelson, Katrin Beutnam, Chris Hirata, Klaus Hoveheid, Aaron Roodman, Uros Seljak, Anze Slosar, Mark Trodden

Executive Summary

Cosmic surveys provide crucial information about high energy physics including strong evidence for dark energy, dark matter, and inflation. Ongoing and upcoming surveys will start to identify the underlying physics of these new phenomena, including tight constraints on the equation of state of dark energy, the viability of modified gravity, the existence of extra light species, the masses of the neutrinos, and the

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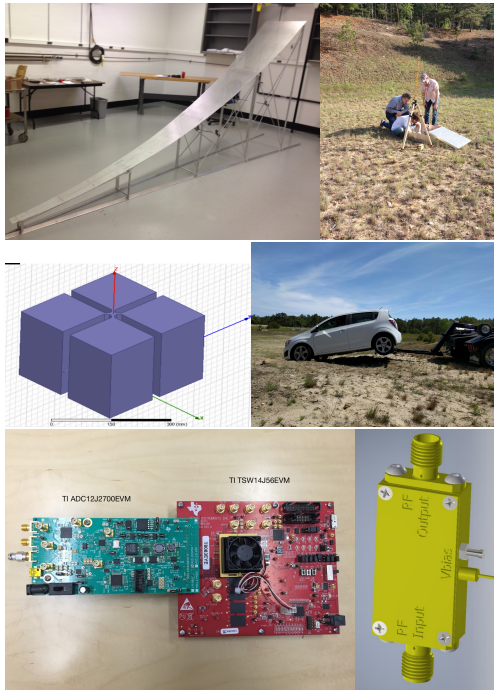


Looking forward

- ▶ LSST our priority for the next decade
- ▶ Instrumentation Division a particular strength and opportunity for cosmology group
- ▶ We secured two LDRDs to investigate BNL's role in post-DESI/post-LSST era: one science, one instrumentation
- ▶ We have identified 21-cm cosmology as a rare opportunity:
 - ▶ Science is compatible with P5 goals: early dark energy, neutrino mass and inflationary properties are accessible
 - ▶ No other agency in US currently funds this particular science with 21-cm technique
 - ▶ Pioneers in this field inside the DOE lab complex
 - ▶ Potentially extremely cost-effective for LSS at $z > 2$
 - ▶ Unique capabilities at BNL from its expertise in RF technology (NSLS, Accelerator Test Facility, Collider Accelerator Dept), thin film SC, etc.
 - ▶ One of the three possibilities for medium-term experiments proposed by CV DE committee
 - ▶ Potentially very synergistic with LSST in terms of science via cross-correlations to calibrate photo-zs

BMX Demo

- ▶ Technology demonstrator built at BNL
- ▶ Goals:
 - ▶ Investigate differencing techniques and software defined radio techniques
 - ▶ Demonstrate simultaneous operation as single dish and interferometer using tone injection to monitor gain
 - ▶ Demonstrate system temperature
 - ▶ Demonstrate RFI and foreground rejection
- ▶ University collaborators from Michigan, Arizona and Princeton
- ▶ Take part in CV process to design a real experiment
- ▶ Chris Sheehy will come as Goldhaber Fellow in September
- ▶ Slosar+Sehgal won as BNL/SB seed grant award for a student



Postdoc problem

- ▶ All postdocs will leave by end of 2016
- ▶ We have two faculty level researchers having leadership roles in LSST WGs: SAWG, LSSWG
- ▶ There two WG have responsibilities within DESC to deliver basic scientific results following the task outlined by the DESC SRM (see talks by SLAC on DESC)
- ▶ The other co-convenors of these two groups are University people
- ▶ **Now it is the right time that we contribute to the execution of SRM. A postdoc working with WG leads is essential.**

Personnel

- ▶ Nomerotski: 0.75 \rightarrow 1.0 FTE in FY17 on LSST
- ▶ Sheldon: 0.8 DES + 0.2 LSST \rightarrow 0.5 DES + 0.5 LSST in FY17
- ▶ Slosar: 0.05 e/BOSS, 0.05 DESI, 0.1 21-cm, 0.8 LSST

		k\$					
Thrust Dark Energy		FY14 1075	FY15 1100	FY 16 975			
		Scenario A			Scenario B		
Year	FY16	FY17	FY18	FY19	FY17	FY18	FY19
Cost (k\$)	975	975	975	975	975	1420	1465
FTEs	4.48	3.0	2.5	2.0	3.0	3.9	3.9

- ▶ We are loosing Slosar's EC funding and Nomerotski start-up LDRD funding
- ▶ In scenario A we need additional funding by FY19 even in case of partial DESC operations support for Sheldon
- ▶ In scenario B, we can afford one postdoc

Final slide

- ▶ With just three members we have the highest per-capita leadership roles in DESC
- ▶ Highly complementary roles: Nomerotski (instrumentation, project linkage), Sheldon (weak lensing), Slosar (large scale structure)
- ▶ We are very visible in the community: averaging one community workshop per year per member
- ▶ Our coupling to Instrumentation Division leverages our usefulness in a way that cannot be replicated at a different lab



generic cosmology group



BNL cosmology group: shoot any one and the music stops